European Innovation Council

CHALLENGE GUIDE

PATHFINDER CHALLENGE Solar-to-X devices for the decentralized prosumption of renewable fuels, chemicals and materials as climate change mitigation pathway

EIC Work Programme reference: HORIZON-EIC-2024-PATHFINDERCHALLENGES-01
Call deadline date: 16 October 2024
EIC Programme Manager: Carina Faber

The EIC will hold an Info Session on this Pathfinder Challenge call on March 20, 2024, between 09:00 and 13:00 CET. Participants can access the meeting as guests at https://webcast.ec.europa.eu/information-day-eic-work-programme-2024-pathfinder-challenges-2024-03-20.
Participation in the meeting, although encouraged, is optional and is not required for the submission of an application. A recording of this Info Session will be made available on the same URL. Notifications of additional dissemination events can be found at https://eic.ec.europa.eu/events/save-date-european-innovation-council-pathfinder-challenges-work-programme-2024-info-day-2024-03-20_en.

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1. About this document

The Challenge Guide serves as guidance and background for the common understanding, participation rules and obligations for the EIC beneficiaries that are involved in the Challenge Portfolio. Contractual Obligations are further detailed in the EIC Work Programme 2024 https://eic.ec.europa.eu/system/files/2023-12/EIC-workprogramme-2024.pdf

The Challenge Guide is a guidance document accompanying a Pathfinder Challenge call for proposals to provide further information about how "Portfolio Considerations" will be taken into account in the evaluation of proposals.

The Challenge Guide is prepared by and under the responsibility of the relevant EIC Programme Manager (information about the EIC Programme Managers is available on the EIC Website https://eic.ec.europa.eu/eic-communities/eic-programme-managers_en). It complements the Scope, Specific Objectives and/or Specific Conditions set out in the EIC Work Programme by a description of the portfolio considerations and how a portfolio will be built. The presentation provided by the Programme Manager during the Info Day will give applicants a further opportunity to understand the background of the call, and to ask questions to the Programme Manager. In no case does the Challenge Guide contradict or supplant the Work Programme text.

Following the selection of a proposal to be funded under the Challenge, the Programme Manager will work together with the consortia of the selected projects to develop a common roadmap with a strategic plan for the Challenge. This roadmap/ strategy plan will integrate the activities and milestones of the individual projects into a shared set of objectives and activities across and beyond the projects. The roadmap serves as a common basis for the project portfolio and may affect the project implementation - including possible adjustments, reorientations, or additional support to projects. The roadmap will be updated in light of emerging results or issues during the implementation.

2. Scope and objectives of the Challenge as defined in the Work programme

This section is a copy of the Challenge call in the EIC work programme text. Proposals to this Challenge are expected to explain how they relate to and intend to go beyond the state-of-the-art, and how they interpret and contribute to the objectives of the Challenge.

2.1 Background and scope

There are currently quite mature technologies tested on industrial pilot scale to provide synthetic fuels and chemicals from renewable energy sources via a sequence of independent energy and chemical conversion steps (Power-to-X or Carbon Capture and Utilization technologies). However, energy losses during the different steps (e.g., electricity production or thermochemical conversion) make the process highly energy intense. Also, the provision of affordable, renewable electricity at the needed scale is challenging. A potential workaround to this bottleneck is the development of devices which directly convert solar energy and abundantly available molecules (such as water or carbon oxides) into liquids and gases – within a single device. These so-called solar-to-X technologies avoid the beforehand conversion of solar energy into electricity and reduce the complexity of the process by a complete integration of the different steps. Solar-to-X technologies, also called artificial photosynthesis or solar fuel technologies, support the vision of a decentralized, local energy and production system with a local provision of the needed resources. In this vision, communities become not only prosumers of electricity, but also of fuels, chemicals and materials.

In this Challenge, solar-to-X technologies must address societal needs not already sufficiently covered by other energy technologies. The developed technologies should demonstrate how they can be embedded in the full functional value chain from generation to use, be self-sustaining in the long-run and provide a win-win opportunity for prosumers and the environment. The objective is to make progress towards synthetic fuels and chemicals technologies which integrate all necessary conversion steps into a single device, and which are solely and directly driven by solar energy. Devices which are driven by electricity or heat are not the focus of this Challenge – except for radically new electrolyzer designs beyond incremental R&D on mature electrolyzer designs. Partially integrated systems, where the overall balance of plant is not significantly simplified (e.g., PV-assisted photoelectrochemical devices) are not within the scope of this Challenge. The use of sacrificial agents has to be avoided and the desired product has to go beyond hydrogen and carbon monoxide. To summarize, this Challenge focusses on: i) Novel electrolyzer designs showing a significantly simplified balance-of-plant compared to mature electrolyzer designs; ii)Fully-integrated PV-EC devices, with electrochemical conversion (EC) and photovoltaic unit (PV) combined in a single device; iii)Photosynthetic devices converting directly sunlight and simple feedstock molecules into a fuel or chemical (e.g., Photoelectrochemical devices, Particulate systems, Biohybrid photosynthetic devices, Thermally-integrated photosynthetic devices, etc.); iv)Solar-driven biological conversion devices (e.g., solar cell factories).

This Challenge is directly relevant to the objectives of the European Green Deal and Repower EU.

2.2 Specific objectives

Project proposals should address one (and only one) of the following three areas:

Area 1: Standalone solar-to-X device development

Projects should address all of the following specific objectives:

- Develop standalone solar-to-X devices, converting sunlight and simple, low-energy molecules such as water, carbon oxides or N2 (non-exhaustive list) into fuels, chemicals and materials.
- Enable simplified production chains where one directly goes from simple feedstock to complex products, beyond hydrogen or carbon monoxide.
- Design solar-to-X systems that can operate independently, allowing communities and remote areas to have access to reliable and sustainable energy sources and a local production and utilization of chemicals and fuels.
- The developed devices have to reach at least TRL 4 within a 3-4 year project runtime.

Area 2: Benchmarking and common metrics development for solar-to-X devices

Projects should address all of the following specific objectives:

- Develop common metrics, protocols and equipment to enable a fair and standardized comparison between technologies within the same class, as well as between different technology classes in the field of solar-to-X (see Area 1 for the different technology categories).

- Develop a holistic framework by identifying key performance indicators common to the different categories, while considering unique features of each category. It is required to develop metrics, protocols and equipment for multiple solar-to-X device architectures (aligned with Area 1).
- Devices stemming from area 1 should serve as a portfolio-own testbed to validate the developed methodologies, protocols and equipment in practice. Standards for solar-to-X devices can (and should) build on existing ones.
- Acceptance of the developed metrics and protocols by a broad range of stakeholders within the diverse research communities must be ensured from the beginning, by e.g., co-creation workshops, extensive outreach activities, etc.

Area 3: Understanding fundamental mechanisms by means of computational materials science

Projects should address all the following specific objectives:

- Explore fundamental phenomena crucial to multiple device architectures to enable next-generation solar-to-X devices.
- Drive forward the one-to-one comparison between theory at the atomistic level and experiment. Developing more accurate and less resource-demanding quantum mechanical methods is highly encouraged.
- Bridge the scales from describing properties at the atomic, mesoscopic up to the macroscopic device level within a multiscale approach.
- Adopt a holistic approach to exploring phenomena applicable to multiple solar-to-X device architectures (aligned with area 1). Devices stemming from area 1 should serve as a portfolio-own testbed to validate the developed theoretical models.

2.3 Expected outcomes and impacts

This Challenge addresses the development of devices - their enabling technologies and use cases - that store sunlight directly on the long term in the form of fuels and chemicals to enable a decentralized energy, transport, and production system.

The portfolio of projects selected under this Challenge is expected to collectively:

- cover Areas 1,2 and 3: There is a strong need to go from the pure concept to next maturity level by developing devices running at elevated timeframes and efficiencies (Area 1). To ensure a fair and honest comparison between the developed devices, common metrics, key performance indicators and standardised protocols must be developed and tested (Area 2). At the same time, fundamental mechanisms that are common to the different device architectures are not fully understood and require dedicated exploration (Area 3). Combining these three aspects in a single portfolio of different projects with close interaction and a commonly developed vision is expected to significantly speed up innovation in the field of solar-to-X.
- identify the most impactful end products and application cases (both on an environmental and economic level): Renewable fuels and chemicals provide the opportunity to couple diverse sectors, including the energy, chemical and transport sector, construction, agriculture or the food and feed sector. By choosing a specific material, chemical or fuel, diverse application scenarios can be addressed by the different projects. Future application scenarios may include remote locations (f. ex. ammonia synthesis for precision farming), single buildings, energy communities in cities or off-grid communities (e.g., devices integrated in architecture), etc.

Concerning environmental and economic impacts:

- The overall system must be cost-efficient and show a simplified balance-of-plant compared to current solutions, e.g., the combination of photovoltaics and an electrolyzer unit.
- The feedstock for the desired product must be sourced locally, preferably valorizing waste streams and solar energy.
- Projects should promote the use of abundant and sustainable resources in the fabrication of solar-to-X devices, minimizing the reliance on rare or expensive materials.
- Proposals should clearly identify a (future) market need and address it with the proposed technology.

Portfolio composition: The applicants of Area 1 should specifically mention to which of the technological areas their technology belongs (Novel electrolyzer designs, Fully-integrated PV-EC, Photosynthetic devices, Solar-driven biological conversion devices).

2.4 Specific conditions

Technologies starting from an energy-rich feedstock, such as biomass, and proposals that only address parts of the full solar-to-X chain (e.g., half reactions) will not be considered.

3 Portfolio considerations for the evaluation of applications to the Challenge

This section describes how portfolio considerations will be taken into account in the second stage of the evaluation. For more details of the full evaluation process please refer to the EIC Work Programme.

3.1 Categories and components values

The objective of this Challenge portfolio is to develop, within the given timeframe of the projects, standalone solar-to-X devices at the integrated small-scale prototype level with auxiliary systems laboratory validated (TRL 4). The portfolio will also develop common metrics, key performance indicators and standardised tests to enable fair benchmarking procedures. At the same time, fundamental mechanisms that are common to different device architectures will be explored. Accordingly, the projects of the portfolio will be classified into three Areas, complementing and cross-fertilising each other.

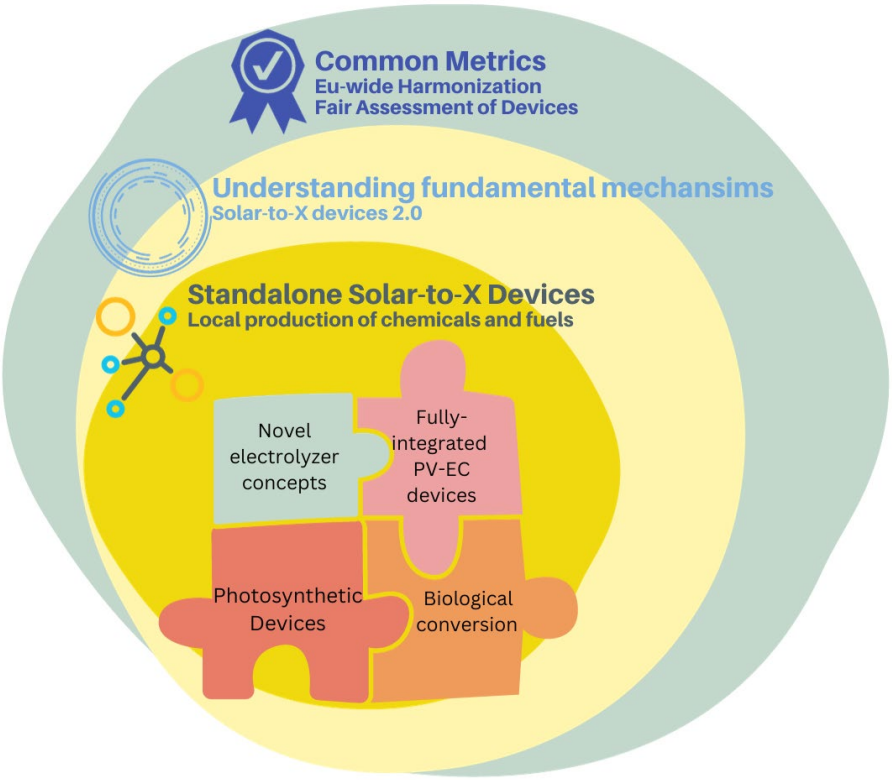

Fig 1.: Scope of the present EIC Challenge portfolio. Core technological development projects on solar-to-X technologies within the portfolio are accompanied by computational material science to explore underlying fundamental mechanisms. Common metrics and measurement tools are promoted at all levels and embed the challenge portfolio projects into a shared assessment framework.

The portfolio-building process will be based on the preliminary mapping of the proposals to one of the following three areas:

1) Standalone solar-to-X device development.
2) Benchmarking and common metrics development for solar-to-X devices.
3) Understanding fundamental mechanisms by means of computational materials science.

Within Area 1), the proposals will be further mapped to one of the following four device categories:

i) Novel electrolyzer designs,

ii) Fully-integrated PV-EC devices,

iii) Photosynthetic devices,

iv) Solar-driven biological conversion devices.

The device category of Photosynthetic devices will be further divided into four sub-device categories: Photo(electro)chemical devices, Particulate systems, Biohybrid devices and Thermally-integrated devices.

Applicants must clearly indicate:

1) to which Area and

2) to which device category they intend to apply (Area 1 proposals) or to which device category the developed tools (Area 2 and 3 proposals) apply, respectively.

Table summarizing the device category.

	Electricity-driven devices		**Solar-driven devices**				
Device categories	Novel electrolyzer systems	Fully-integrated PV-EC	Photosynthetic devices				Solar-driven biological conversion
Device sub-categories			Photo(electro) chemical (PEC) devices	Particulate systems	Biohybrid devices	Thermally-integrated	
Description	Significantly simplified balance-of-plant, beyond incremental R&I on existing technologies	Electrodes and PV unit in a single device	e.g., artificial leave, buried junction; biomolecular PEC devices are also included (electrodes functionalized with enzymes), etc.	Particle suspensions, nanosheets, etc.	Electrodes + living microbial cells	Heat + light management	Solar microbial cell factories, precision fermentation, Secretion of product molecules from the cell

3.2 Summary portfolio building approach

The evaluation committee will compose a balanced and diverse Challenge portfolio covering the three aforementioned areas. During the portfolio building process, first Area 1 projects will be selected.

Within Area 1, as many as possible different device categories shall be represented in the Challenge portfolio. The device categories i, ii and iv should be at least covered with one project, the remaining ones are attributed to device category iii, Photosynthetic devices, and its sub-categories to create as much diversity as possible. Within and among the device categories of Area 1, the evaluation committee will look at complementarities among the projects (such as product, feedstock, sector, application, energy input, see below table). The goal is to maximise the overall impact of the Challenge portfolio by addressing as much complementarities by the different portfolio projects.

For Area 2 and Area 3, portfolio considerations foresee that a single project will be sufficient per Area in the final portfolio composition. All the abovementioned statements are conditional on excellency of proposals, available budget and other factors. In both areas, the project with the highest relevance (Applicability to the device categories and sub-device categories selected in Area 1) will be chosen.

Starting from the highest ranked proposal, a portfolio of proposals will be selected according to the principles described above. This implies that proposals which the evaluation committee considers to be very similar to a proposal already included in the portfolio will not be selected. Consequently, this means that the projects selected for funding after the second step is expected to differ from the ranking list established from the first step (score-based ranking after assessment of each proposal separately).

The following table summarises the guiding principles for the envisioned portfolio building approach. It lists the categories that will be used in the portfolio building and their values/components.

<table>
<tr><td colspan="2"></td></tr>
<tr><td>Area 1:
Standalone solar-to-X device development</td><td>Complementarity</td></tr>
<tr><td rowspan="4">Targeted device categories:

i) Novel electrolyser designs
ii) Fully-integrated PV-EC devices
iii) Photosynthetic devices
a. Photo(electro)chemical devices,
b. Particulate systems,
c. Biohybrid devices,
d. Thermally-integrated devices;
iv) Solar-driven biological conversion devices</td><td>Feedstock during operation (Water, CO_2, etc.)</td></tr>
<tr><td>Product scope (Ethylene, ammonia, proteins, etc.)</td></tr>
<tr><td>Targeted sector(s) (Chemicals, Transport, Energy, Agriculture, Feed, etc.)</td></tr>
<tr><td>Future application scenario(s) (Remote location, city rooftops, etc.)</td></tr>
<tr><td>Necessary energy input(s) (solar light, electricity, heat, etc.)</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Area 2:
Benchmarking and common metrics development for solar-to-X devices</td><td>Complementarity</td></tr>
</table>

Devices stemming from Area 1 should serve as a portfolio-own testbed to validate the developed methodologies, protocols and equipment in practice. Standards for solar-to-X devices can (and should) build on existing ones.	**Applicability to which of the device categories (and sub-device) as developed in Area 1**
Area 3: Understanding fundamental mechanisms by means of computational materials science	**Complementarity**
Devices stemming from Area 1 should serve as a portfolio-own testbed to validate the developed theoretical models.	**Applicability to which of the device (and sub-device) categories as developed in Area 1**

It is advised for projects to provide a completed version of one of the below tables applying to their area in order to facilitate the portfolio building process. However, if projects do not provide such kind of a summary, their evaluation will not be negatively influenced.

Area 1: Standalone solar-to-X device development						
Project acronym	**Device Category (+ Subcategory)**	**Feedstock**	**Energy input(s)**	**Product(s)**	**Sector**	**Application scenario**

Area 2: Benchmarking and common metrics development for solar-to-X devices	
Project acronym	**Applicability (sub-)device categories Area 1**

Area 3: Understanding fundamental mechanisms by means of computational materials science	
Project acronym	**Applicability (sub-)device categories Area 1**

4. Implementation of the Challenge portfolio

Once funded, projects will be expected and obliged to work collectively during the implementation of their projects under the guidance of an EIC Programme Manager. This section summarises some of the key aspects of this pro-active management which applicants should consider in preparing their proposals.

4.1 Proposal preparation and Grant negotiations

Applicants may be requested to make amendments to their proposed project in order to enhance the impact of the portfolio. Such changes may for instance include additional tasks to undertake common/ joint activities (workshops, data exchanges, joint research, etc) with other projects in the portfolio.

Based on past experience, it is advised to foresee in the proposal a dedicated work package for portfolio activities and to allocate for this Challenge at least 10 person-months (see below for the purpose and examples of such activities. You may propose concrete activities or remain generic in your description).

If you fail to do this during proposal time, your proposal will not be scored lower during the evaluation, but in case your proposal is selected for grant agreement preparation, you will be requested to add the portfolio work package to your grant agreement. Please be aware that in that case the maximum grant you receive will not change, and you will need to find the resources for portfolio activities within the foreseen project budget.

4.2 Challenge portfolio roadmap/ strategy plan

This Challenge portfolio aims at promoting the development of solar-to-X prototype devices showing consistently measured and reproducible performances, while enabling the development of next generation devices.
Following the selection of proposals to be funded under the Challenge, the Programme Manager will work together with the consortium of the selected projects to develop a common strategy plan/roadmap for the Challenge. This plan will integrate the activities and milestones of the individual projects into a shared set of specific objectives and activities across and beyond the projects. The roadmap serves as a common basis for the project portfolio and may affect the project implementation - including possible adjustments, reorientations, or additional support to projects. The roadmap will be updated in light of emerging results or issues during the implementation. The objectives can be revised, for instance based on projects' unexpected achievements, new technology trends, external inputs (other projects, new calls…).

In particular, the Challenge roadmap/ strategy plan will include activities on technology, regulation, transition of technology to innovation, and communication and dissemination. These activities may be reinforced during the implementation with additional funding and expertise through pro-active management.
Non-exhaustive examples of activities towards the above-mentioned aims are:

Technology
A close collaboration and interaction of the portfolio projects on advances, drawbacks and key findings of their technological developments is expected to strongly accelerate innovation in the field. Integrative portfolio activities are encouraged that result in collective insights amongst the projects.
Providing access to Open Innovation Test Beds and other research infrastructure.

Regulation
Portfolio activities that support, inform, participate in discussions around, or identify gaps in on-going legislative processes (e/g development of standards) for EU carbon markets (e/g CCU) and markets deploying fossil-free fuels, chemicals or materials are encouraged.

Transition of technology to (social) innovation
To single out a clear added value of the developed solar-to-X technologies in the complex landscape of already existing energy technologies and to ensure the development of technologies with a clearly identified impact, diverse activities are already foreseen by the Programme Manager:

- **Techno-sustainability assessment**: The EIC currently develops, together with VITO, an in-house methodology for the holistic and systematic evaluation of selected technical, environmental, economic and social indicators for a standardized assessment of solar-to-X devices. This framework offers both flexibility and standardization to guide interpretation and inter-comparability. Projects are asked to actively participate to this assessment following the templates currently under development. Under the guidance of the Programme Manager, goals are to commonly:
    - develop a clear understanding of the potential sustainability impact of solar fuel innovation,
    - get insight into the applications that need to be targeted within this domain to guide decision makers and identify the possible societal impact,
      guide research in this field towards the most sustainable configurations at early stage.
- **Scenario building, societal challenges and opportunities:** to attract further investments and to establish a broad understanding of this field, a scenario building exercise is planned. The goal is to develop and promote scenarios based on a

decentralized, local production and consumption of fuels, chemicals and materials – a scenario still under-represented in current pathways for climate change mitigation. Moreover, the portfolio projects will work together on societal challenges and opportunities encountered by solar-to-X technologies under the guidance of the Programme Manager. The future challenge portfolio represents an ideal pan-European test-bed for such kind of studies, the latter representing a highly relevant portfolio activity outcome for the solar-to-X community in general.

Communication and dissemination

The Challenge portfolio projects are supposed to represent a leading flagship group on solar-to-X devices driving forward the topic through open collaboration with other EU and national projects. Outreach activities should gather a broad community working on diverse aspects of solar-to-X devices around a commonly developed understanding of the respective to accelerate innovation in the field. Attracting public and private investors and to increase public awareness in general is a desired outcome of the challenge portfolio.

Mandatory outreach activities identified by the Programme Manager include:

- A Challenge portfolio **kick-off event** in year one of the portfolio activities, preferentially in the Brussel's EU environment, among others:
    - Demonstrating the State-of-the-art of the different involved domains,
    - Showcasing the different portfolio projects to be started,
    - Giving place to a broad stakeholder community, including contributions from leading representatives from academia, industry, policy and society,
    - Starting a scenario building exercise to scout what the world could look like tomorrow assuming a wide application of these technologies.
- A Challenge portfolio **final event** at the end of the runtime preferentially in the Brussel's EU environment, among others:
    - Showcasing the outcome of the portfolio activities, in the best case by presenting the actual prototypes and innovative concepts to communicate the achieved results and their impact on society to a broad public including leading representatives from academia, industry, policy and society.
- A **webinar on the international level every around four times by year** organised by the Challenge portfolio members on diverse topics relevant for the solar-to-X community, being inclusive, interdisciplinary and reaching out to the academic community as well as industry, innovators and policy makers.

Apart from outreach activities, internal exchange of both advances and barriers is of outmost importance and will be implemented via:

- An **internal kick-off meeting** to align common milestones and goals,
- **Regular portfolio meetings** to discuss progress.

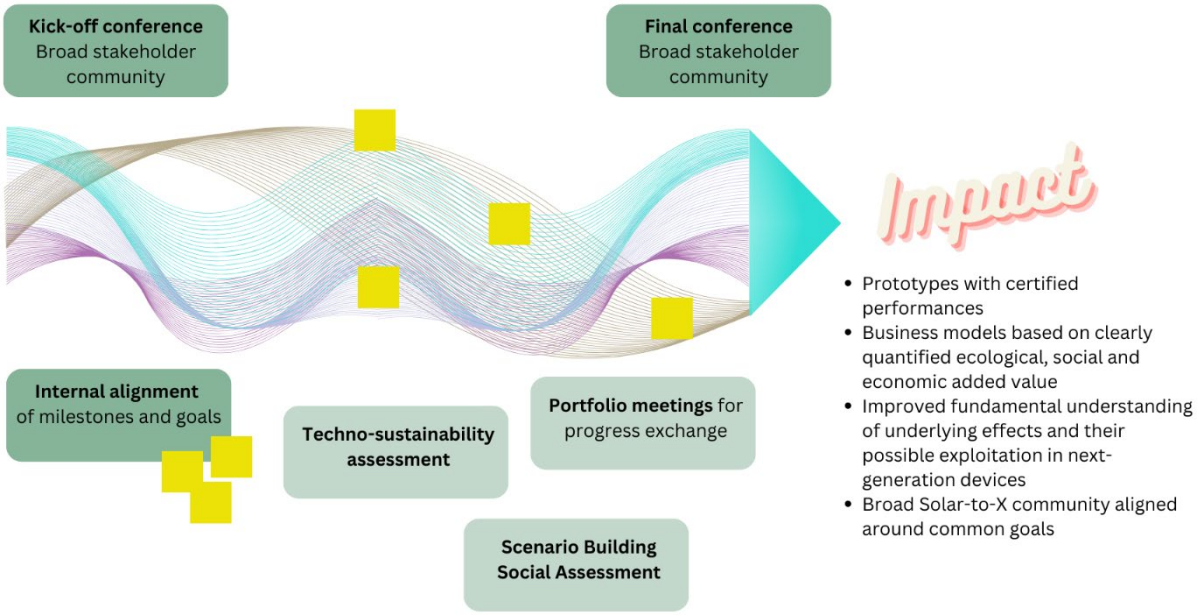

Fig. 2: Exemplary roadmap of the Challenge portfolio, including milestones and goals defined by the Programme Manager (green) and milestones/activities to be defined together with the Challenge portfolio members (yellow). The final goal is to show clear impact at the end of the projects' runtime, by delivering first prototypes with certified performances, sustainable and economically-viable business models, an improved understanding of underlying mechanisms and by nourishing a broad solar-to-X community.

These tasks require the active participation of portfolio members to a series of meetings called for and steered by the Programme Manager. Portfolio projects will be expected to exchange information on the proposed research methodologies, experimental tests, techno-economic input data and relevant results achieved, in order to collectively use the available resources. This exchange of data between portfolio members can enhance the potential of individual projects, use of results originating from the analysis of common databases, as well as their chances to establish key partnerships. The exchange of information for the purpose of EIC portfolio activities will fall under the conditions and non-disclosure obligations as specified in the EIC Work Programme 2024.

4.3 Tools through which projects can receive additional support

Projects in the portfolio may be offered additional support, either individually or collectively, in order to reinforce portfolio activities or explore the transition to innovation. Such additional support includes:

- Booster grants of up to €50k (see Annex 5 of the EIC Work Programme)
- Access to additional EIC Business Acceleration Services (see https://eic.ec.europa.eu/eic-funding-opportunities/business-acceleration-services_en)

- Access to the Fast Track to the EIC Accelerator, which would follow a project review (see Annex 3 of the EIC Work Programme)
- Interactions with relevant projects and initiatives outside the portfolio, including other EU funding initiatives as well as those supported by national, regional or other international bodies.